CLAIMS

1. Apparatus comprising:

a capsule, adapted to be swallowed by a subject, and comprising:

at least one radiation source, adapted to emit radiation having an energy of at least 10 keV; and

at least one photon detector, adapted to detect photons generated responsively to the emitted radiation, the photons having an energy of at least 10 keV; and

a control unit, adapted to analyze data regarding the photons in order to generate information useful for identifying a clinically-relevant feature of a gastrointestinal (GI) tract of the subject.

2. The apparatus according to claim 1, comprising an oral contrast agent, adapted to be administered to the subject.

3. The apparatus according to claim 1, comprising an oral agent having a high Z, adapted to be administered to the subject.

4. The apparatus according to claim 1, comprising an oral agent adapted to be administered to the subject, the agent selected from the list consisting of: a contrast agent and a high Z agent, wherein the agent comprises ferromagnetic particles, and wherein the capsule comprises a magnet, adapted to attract the ferromagnetic particles to the capsule.

5. The apparatus according to claim 1, wherein the radiation source comprises a miniature X-ray generator.

6. The apparatus according to claim 1, wherein the radiation source comprises a radioisotope.

7. The apparatus according to claim 1, wherein the radiation source is adapted to emit gamma rays.

8. The apparatus according to claim 1, wherein the radiation source is adapted to emit X-rays.

9. The apparatus according to claim 1, wherein the control unit is adapted to analyze a time derivative of the data in order to generate the information.

10. The apparatus according to claim 1, wherein the radiation source comprises at least one collimator, adapted to collimate the radiation emitted by the radiation source.

11. The apparatus according to claim 1, wherein the photon detector comprises at least one collimator, adapted to collimate the photons detected by the photon detector.

12. The apparatus according to claim 1, wherein the control unit is adapted to distinguish between gas in the GI tract and the clinically-relevant feature.

13. The apparatus according to claim 1, wherein the control unit is adapted to analyze X-ray fluorescence (XRF) photons generated responsively to the emitted radiation.

14. The apparatus according to claim 1, wherein the control unit is adapted to analyze X-ray fluorescence (XRF) photons generated responsively to the emitted radiation, and Compton backscattered photons generated responsively to the emitted radiation.

15. The apparatus according to claim 1, wherein the capsule comprises an acceleration sensor.

16. The apparatus according to claim 1, comprising an external data-recording unit, adapted to remain outside a body of the subject, wherein the capsule is adapted to wirelessly transmit information to the data-recording unit while the capsule is in the GI tract.

17. The apparatus according to claim 1, wherein the capsule comprises an agent selected from the list consisting of: a contrast agent and a high Z agent, and wherein the capsule is adapted to store the agent and release the agent in an area of clinical interest in the GI tract.

18. The apparatus according to claim 1, comprising an agent-storage capsule comprising an agent selected from the list consisting of: a contrast agent and a high Z agent, the agent-storage capsule adapted to store the agent and release the agent in an area of clinical interest in the GI tract.

19. The apparatus according to claim 1, wherein the capsule comprises a pressure sensor.

20. The apparatus according to claim 1, wherein the data regarding the photons include data for one or more predefined photon energy windows, and wherein the control unit is adapted to analyze the energy window data.

21. The apparatus according to claim 1,

wherein the data regarding the photons include a number of the photons per time interval,

wherein the photon detector is adapted to count the detected photons, and

wherein the control unit is adapted to analyze the counted number of photons.

22. The apparatus according to any one of claims 1-21, wherein the control unit is adapted to estimate a distance from a site of the capsule to a wall of the GI tract.

23. The apparatus according to claim 22, wherein the control unit is adapted to estimate the distance using an algorithm in which there is an inverse relationship between the distance and a count of the detected photons.

24. The apparatus according to claim 23, wherein the control unit is adapted to analyze Compton backscattered photons generated responsively to the emitted radiation.

25. The apparatus according to claim 24, comprising an oral contrast agent, adapted to be administered to the subject, wherein the control unit is adapted to estimate the distance by estimating a depth of the contrast agent between the site of the capsule and the wall of the GI tract responsively to the analysis of the Compton backscattered photons.

26. The apparatus according to claim 22, wherein the control unit is adapted to estimate the distance using an algorithm in which there is a direct relationship between the distance and a count of the detected photons.

27. The apparatus according to claim 26, wherein the control unit is adapted to analyze X-ray fluorescence (XRF) photons generated responsively to the emitted radiation.

28. The apparatus according to claim 27, comprising an oral agent having a high Z, adapted to be administered to the subject, wherein the XRF photons are generated by the oral agent responsively to the emitted radiation, and wherein the control unit is adapted to estimate the distance by estimating a depth of the agent between the site of the capsule and the wall of the GI tract responsively to the analysis of the XRF photons.

29. The apparatus according to any one of claims 1-21, wherein the radiation source is adapted to emit the radiation from the capsule only a portion of a time that the capsule is in the GI tract.

30. The apparatus according to claim 29, wherein the capsule comprises a sensor, adapted to sense a parameter indicative of possible imminent motion of the capsule in the GI tract, and wherein the radiation source is adapted to emit the radiation from the capsule responsively to the sensing of the parameter by the sensor.

31. The apparatus according to claim 29, wherein the radiation source comprises a miniature X-ray generator, configured to emit the radiation only during the portion of the time.

32. The apparatus according to claim 29,

wherein the radiation source comprises a radioisotope,

wherein the capsule comprises a radiation shield, and

wherein the capsule comprises an actuator, adapted to move at least one of the radiation source and the shield, such that the shield does not block the radiation emitted from the radiation source during the portion of the time.

33. The apparatus according to claim 32, wherein the capsule comprises a plurality of collimators, and wherein the collimators and the shield are configured such that, at any given time, the radiation emitted by the radiation source passes through less than all of the collimators.

34. The apparatus according to claim 32, wherein the capsule comprises a rod, wherein the radiation source is coupled to the rod, and wherein the actuator is adapted to move the rod in order to move the radiation source.

35. The apparatus according to claim 34, wherein the capsule comprises at least one spring, and wherein the rod and spring are configured to form a mechanical oscillator.

36. The apparatus according to any one of claims 1-21, wherein the capsule comprises an inflatable balloon, adapted to inflate around the capsule.

37. The apparatus according to claim 36, wherein the balloon is configured such that the capsule moves towards a center of the balloon upon inflation thereof.

38. The apparatus according to claim 36, wherein the balloon is configured to inflate when the capsule reaches an area of clinical interest within the GI tract.

39. The apparatus according to claim 36, wherein the balloon comprises a valve, adapted to open a certain period of time after the capsule reaches the area of clinical interest, thereby allowing the balloon to deflate.

40. The apparatus according to claim 36, wherein the control unit is adapted to estimate a wall distance from a capsule site of the capsule to a wall of the GI tract by calculating a sum of (a) a first distance within the balloon from the capsule site to a balloon site on a surface of the balloon and (b) a second distance from the balloon site to the wall of the GI tract.

41. The apparatus according to claim 40, wherein the control unit is adapted to calculate the first distance by measuring and analyzing changes in Compton backscattered photon counts detected by the photon detector.

42. The apparatus according to claim 40, wherein the control unit is adapted to calculate the first distance responsively to a size of a Compton backscattering projection detected by the photon detector.

43. The apparatus according to claim 40, wherein the surface of the balloon comprises point particles comprising a high density material, and wherein the control unit is adapted to calculate the first distance by measuring and analyzing X-ray fluorescence (XRF) photon counts detected by the photon detector.

44. The apparatus according to claim 40, wherein the surface of the balloon comprises radiation point sources, and wherein the control unit is adapted to calculate the first distance by measuring and analyzing radiation emitted from the point sources and detected by the photon detector.

45. The apparatus according to claim 40, wherein the control unit is adapted to calculate the second distance by analyzing X-ray fluorescence (XRF) photon counts detected by the photon detector.

46. The apparatus according to any one of claims 1-21, wherein the GI tract includes a colon of the subject, and wherein the control unit is adapted to analyze the data in order to generate the information useful for identifying the clinically-relevant feature of the colon.

47. The apparatus according to claim 46, wherein the capsule comprises:

electrodes coupled to an external surface of the capsule; and

a pulse generator,

wherein the control unit is adapted to drive the pulse generator to apply an electrical signal to the colon capable of inducing a mass movement in the colon.

48. The apparatus according to claim 46, wherein the control unit is adapted to generate the information regarding a geometry of muscles of the colon.

49. The apparatus according to any one of claims 1-21, wherein the control unit is adapted to generate a graphical representation of the information.

50. The apparatus according to claim 49, wherein the control unit is adapted to generate the graphical representation by generating a series of morphologies in time.

51. The apparatus according to claim 49, wherein the control unit is adapted to generate the graphical representation by:

generating a first surface having subdivisions representing respective distances between respective sites of the capsule and respective sites of a wall of the GI tract, and

generating a second surface having pixels, each of which pixels represents a respective difference between one of the subdivisions of the first surface and a plurality of subdivisions neighboring the one of the subdivisions.

52. The apparatus according to claim 51, wherein the control unit is adapted to generate the graphical representation by:

repeatedly generating the second surface at a plurality of points in time, and

displaying an animation of the second surface corresponding to the plurality of points in time.

53. The apparatus according to claim 49, wherein the control unit is adapted to generate the graphical representation with reference to a coordinate system of the subject.

54. The apparatus according to claim 49, wherein the control unit is adapted to generate the graphical representation with reference to a coordinate system of the capsule.

55. The apparatus according to any one of claims 1-21, wherein the at least one photon detector comprises a plurality of photon detectors, arranged to detect photons arriving from a plurality of respective detection directions.

56. The apparatus according to claim 55, wherein the at least one radiation source comprises a plurality of collimators, arranged to emit the radiation in a plurality of respective emission directions corresponding to the detection directions.

57. The apparatus according to any one of claims 1-21, wherein the capsule comprises at least one radiation shield.

58. The apparatus according to claim 57, wherein the at least one shield is configured to prevent radiation from being emitted from the radiation source in directions other than a single confined solid sector relative to a sphere surrounding the capsule.

59. The apparatus according to any one of claims 1-21, wherein the radiation source is adapted to emit radiation having a primary plurality of energy levels, and wherein the control unit is adapted to analyze counts of photons having a secondary plurality of energy levels, different from the primary plurality of energy levels.

60. The apparatus according to claim 59, wherein the radiation source is adapted to emit radiation having first and second energy levels, and wherein the control unit is adapted to analyze a mathematical relationship between (a) a count of the photons detected by the photon detector having a third energy level and (b) a count of the photons detected by the photon detector having a fourth energy level.

61. The apparatus according to claim 60, wherein the relationship includes a ratio of (a) the count of the photons having the third energy level to (b) the count of the photons having the fourth energy level, and wherein the control unit is adapted to analyze the ratio.

62. The apparatus according to claim 60, wherein the control unit is adapted to analyze the relationship to determine an actual, calibrated distance between a site of the capsule and a wall of the GI tract.

63. The apparatus according to any one of claims 1-21, wherein the clinically-relevant feature includes a pathological abnormality of the GI tract.

64. The apparatus according to claim 63, wherein the pathological abnormality includes a polyp.

65. The apparatus according to any one of claims 1-21, wherein the control unit is adapted to analyze Compton backscattered photons generated responsively to the emitted radiation.

66. The apparatus according to claim 65, wherein the control unit is adapted to analyze Compton backscattered photons having an energy level indicative of a backscattering angle of 180 degrees +/- a range parameter that is less than 30 degrees.

67. The apparatus according to claim 66, wherein the range parameter is less than 20 degrees.

68. The apparatus according to claim 67, wherein the range parameter is less than 10 degrees.

69. The apparatus according to any one of claims 1-21, wherein the control unit is adapted to detect that the capsule has reached an area of clinical interest within the GI tract.

70. The apparatus according to claim 69, wherein the area includes the colon, and wherein the control unit is adapted to detect that the capsule has reached the colon.

71. The apparatus according to claim 69, wherein the control unit is adapted to detect that the capsule has reached the area by detecting and analyzing X-ray fluorescence (XRF) photons.

72. The apparatus according to claim 69, wherein the capsule comprises a pH-sensitive element, and wherein the control unit is adapted to detect that the capsule has reached the area responsively to change in pH in the area that affects the pH-sensitive element.

73. The apparatus according to claim 69, comprising a tag adapted to be coupled to an external surface of a body of the subject in a vicinity of an entrance to the area, wherein the control unit is adapted to detect that the capsule has reached the area responsively to a signal emitted by the tag.

74. The apparatus according to claim 69, wherein the capsule comprises a pressure sensor, and wherein the control unit is adapted to detect that the capsule has reached the area responsively to a change in pressure detected by the pressure sensor.

75. The apparatus according to claim 74, comprising a tag adapted to be coupled to an external surface of a body of the subject in a vicinity of an entrance to the area, wherein the control unit is adapted to detect that the capsule has reached the area responsively to (a) a signal emitted by the tag in combination with (b) the change in pressure.

76. The apparatus according to claim 74, wherein the control unit is adapted to detect that the capsule has reached the area by detecting and analyzing X-ray fluorescence (XRF) photons, and responsively to the change in pressure.

77. The apparatus according to any one of claims 1-21, wherein the control unit is adapted to detect a variation of density in tissue of a wall of the GI tract, which variation is indicative of a presence of the clinically-relevant feature.

78. The apparatus according to claim 77, wherein the control unit is adapted to detect the variation when the control unit detects that at least a portion of the capsule is in physical contact with the wall of the GI tract.

79. The apparatus according to claim 77, wherein the at least one photon detector comprises a plurality of photon detectors, and wherein the control unit is adapted to analyze Compton backscattered photon counts from a site of the wall, detected by more than one of the photon detectors.

80. The apparatus according to claim 79, wherein the control unit is adapted to analyze the Compton backscattered photon counts using principal component analysis (PCA).

81. The apparatus according to claim 80, wherein the control unit is adapted to detect the variation of density responsively to a determination that a large fraction of a data variance cannot be described by a single principal component (PC).

82. The apparatus according to any one of claims 1-21, wherein the capsule comprises at least one extending element, adapted, when extended, to maintain the capsule at least a certain distance from a wall of the GI tract.

83. The apparatus according to claim 82, wherein the extending element is configured to extend when the capsule reaches an area of clinical interest within the GI tract.

84. The apparatus according to claim 82, wherein the extending element comprises at least one leg-shaped element.

85. The apparatus according to claim 82, wherein the extending element comprises an expandable ring structure.

86. The apparatus according to claim 82, wherein the extending element comprises an unfolding element.

87. The apparatus according to any one of claims 1-21, wherein the capsule comprises at least one extending element, adapted, when extended, to orient a long axis of the capsule generally parallel to a longitudinal axis of the GI tract.

88. The apparatus according to claim 87, wherein the extending element comprises an expandable flexible chamber.

89. The apparatus according to claim 88, wherein the flexible chamber comprises a super-absorbent hydrogel, and wherein the flexible chamber is adapted to expand when the hydrogel absorbs liquids from the GI tract.

90. Apparatus comprising:

a capsule, adapted to be swallowed by a subject, and comprising at least one photon detector, adapted to detect photons having a detector energy of at least 10 keV; and

a control unit, adapted to analyze data regarding the photons in order to generate information useful for identifying a clinically-relevant feature of a gastrointestinal (GI) tract of the subject.

91. The apparatus according to claim 90, comprising a radiolabeled material adapted to be swallowed by the subject and to emit radiation having a radiolabeled energy, wherein the control unit is adapted to analyze the data regarding the photons having the radiolabeled energy.

92. The apparatus according to claim 90, wherein the photon detector is collimated.

93. The apparatus according to any one of claims 90-92, wherein the control unit is adapted to estimate a distance from a site of the capsule to a wall of the GI tract.

94. The apparatus according to claim 93, wherein the control unit is adapted to estimate the distance using an algorithm in which there is a direct relationship between the distance and a count of the detected photons.

95. Apparatus comprising:

a capsule, adapted to be swallowed by a subject, comprising at least one radiation source, adapted to emit radiation having an energy of at least 10 keV;

at least one photon detector not physically coupled to the capsule, adapted to detect photons having an energy of at least 10 keV; and

a control unit, adapted to analyze data regarding the photons in order to generate information useful for identifying a clinically-relevant feature of a gastrointestinal (GI) tract of the subject.

96. The apparatus according to claim 95, wherein the radiation source comprises at least one collimator, adapted to collimate the radiation emitted by the radiation source.

97. The apparatus according to claim 95, wherein the radiation source comprises a miniature X-ray generator.

98. The apparatus according to claim 95, wherein the radiation source comprises a radioisotope.

99. Apparatus comprising:

a capsule, adapted to be swallowed by a subject, comprising a plurality of photon detectors;

a balloon, adapted, when inflated, to surround at least a portion of the capsule, and comprising at a surface thereof a plurality of radiation sources, adapted to emit radiation having an energy of at least 10 keV, wherein the photon detectors are adapted to detect photons generated responsively to the radiation, the photons having an energy of at least 10 keV; and

a control unit, adapted to analyze data regarding the photons in order to generate information useful for identifying a clinically-relevant feature of a gastrointestinal (GI) tract of the subject.

100. The apparatus according to claim 99, wherein the control unit is adapted to analyze X-ray fluorescence (XRF) photons detected by the photon detectors in order to estimate a distance between a site on the surface of the balloon and a wall of the GI tract.

101. The apparatus according to claim 99, wherein the control unit is adapted to analyze Compton backscattered photons having an energy level indicative of a backscattering angle of 180 degrees +/- a range parameter that is less than 30 degrees.

102. The apparatus according to any one of claims 99-101, wherein the control unit is adapted to analyze incident photons having a same energy as the radiation emitted by the radiation sources.

103. The apparatus according to claim 102, wherein the control unit is adapted to analyze both the incident photons and Compton backscattered photons having an energy level indicative of a backscattering angle of 180 degrees +/- a range parameter that is less than 30 degrees.

104. The apparatus according to claim 102, wherein the apparatus comprises more photon detectors than radiation sources.

105. The apparatus according to claim 102, wherein the control unit is adapted to map the feature by analyzing, in combination, incident photon counts and Compton backscattered photon counts measured by the plurality of photon detectors.

106. The apparatus according to claim 105, wherein the control unit is adapted to map the feature by determining respective locations of the plurality of radiation sources, by analyzing, in combination, incident photon counts and Compton backscattered photon counts measured by the plurality of photon detectors.

107. The apparatus according to claim 106, wherein the control unit is adapted to extrapolate a shape of the surface of the balloon responsively to the respective locations of the plurality of the radiation sources.

108. Apparatus comprising:

a capsule, adapted to be swallowed by a subject, comprising a plurality of photon detectors;

an expandable structure, adapted, when expanded, to surround at least a portion of the capsule, and shaped, when expanded, so as to define a plurality of sites thereof that are not in direct physical contact with the capsule, the sites comprising respective radiation sources, adapted to emit radiation having an energy of at least 10 keV, wherein the photon detectors are adapted to detect photons generated responsively to the emitted radiation, the photons having an energy of at least 10 keV; and

a control unit, adapted to analyze data regarding the photons in order to generate information useful for identifying a clinically-relevant feature of a gastrointestinal (GI) tract of the subject.

109. Apparatus for use with an object of interest, the apparatus comprising:

at least one radiation source, adapted to emit radiation having an energy of at least 10 keV;

at least one photon detector, adapted to detect photons having an energy of at least 10 keV;

a high Z agent, adapted to be placed between the radiation source and the object; and

a control unit, adapted to analyze X-ray fluorescence (XRF) photons emitted by the high Z agent responsively to the emitted radiation, and detected by the at least one

photon detector, in order to estimate a distance between the radiation source and the object.

110. Apparatus for use with an object of interest, the apparatus comprising:

at least one radiation source, adapted to emit radiation having an energy of at least 10 keV;

a contrast agent, adapted to be placed between the radiation source and the object; and

a control unit, adapted to analyze Compton backscattered photons emitted by the contrast agent responsively to the emitted radiation, and detected by the at least one photon detector, in order to estimate a distance between the radiation source and the object.

111. Apparatus for use with an object of interest, the apparatus comprising:

at least one photon detector, adapted to detect photons having an energy of at least 10 keV;

a radiolabeled material, adapted to emit radiation having an energy of at least 10 keV, and to be placed between the photon detector and the object; and

a control unit, adapted to analyze detected photons emitted by the radiolabeled material, in order to estimate a distance between the photon detector and the object.

112. A method comprising:

emitting, from within a gastrointestinal (GI) tract of a subject, radiation having an energy of at least 10 keV;

detecting, from within the GI tract, photons generated responsively to the emitted radiation, the photons having an energy of at least 10 keV; and

analyzing data regarding the detected photons in order to generate information useful for identifying a clinically-relevant feature of the GI tract.

113. The method according to claim 112, comprising administering an oral contrast agent to the subject.

114. The method according to claim 112, wherein emitting the radiation comprises orally administering to the subject a radiolabeled material that emits the radiation.

115. The method according to claim 112, wherein emitting and detecting comprise orally administering a swallowable capsule to the subject, and emitting and detecting from the capsule.

116. The method according to any one of claims 112-115, wherein detecting comprises orally administering a swallowable capsule to the subject, and detecting from the capsule.

117. A method comprising:

detecting, from within a gastrointestinal (GI) tract of a subject, photons having an energy of at least 10 keV; and

analyzing data regarding the detected photons in order to generate information useful for identifying a clinically-relevant feature of the GI tract.

118. A method comprising:

emitting, from within a gastrointestinal (GI) tract of a subject, radiation having an energy of at least 10 keV;

detecting photons having an energy of at least 10 keV; and

analyzing data regarding the detected photons in order to generate information useful for identifying a clinically-relevant feature of the GI tract.

119. A method comprising:

detecting, from a first plurality of points within a gastrointestinal (GI) tract of a subject, photons;

emitting, from a second plurality of points within the GI tract that surround the first plurality of points, radiation having an energy of at least 10 keV, wherein the photons are generated responsively to the emitted radiation and have an energy of at least 10 keV; and

analyzing data regarding the detected photons in order to generate information useful for identifying a clinically-relevant feature of the GI tract.

120. A method comprising:

placing a high Z agent between a first site and a second site;

emitting, from the first site, radiation having an energy of at least 10 keV;

detecting photons having an energy of at least 10 keV; and

estimating a distance between the first site and the second site by analyzing detected X-ray fluorescence (XRF) photons emitted by the high Z agent responsively to the emitted radiation.

121. A method comprising:

placing a contrast agent between a first site and a second site;

emitting, from the first site, radiation having an energy of at least 10 keV;

detecting photons having an energy of at least 10 keV; and

estimating a distance between the first site and the second site by analyzing detected Compton backscattered photons emitted by the contrast agent responsively to the emitted radiation.

122. A method comprising:

placing a radiolabeled material, adapted to emit radiation having an energy of at least 10 keV, between a first site and a second site;

detecting photons having an energy of at least 10 keV; and

estimating a distance between the first site and the second site by analyzing detected photons emitted by the radiolabeled material.